Geothermal Resource Technologies, Inc.

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FORMATION THERMAL CONDUCTIVITY TEST AND DATA ANALYSIS

Analysis for

Tennessee Valley Authority
P.O. Box 1010, CSC 1A
Muscle Shoals, Alabama 35662-1010
(256) 386-2713 • Fax: (256) 386-3529

Test location

Hartselle Utilities
Hartselle, AL

May 8, 2001

Test Performed by

Geothermal Resource Technologies, Inc.

Executive Summary

A formation thermal conductivity test was performed at the Hartselle Utilities site in Hartselle, Alabama. The vertical bore was installed on May 2, 2001 by Mid-South Drilling, Inc. The test unit was attached to the vertical bore on the afternoon of Saturday, May 5, 2001. The collected data was analyzed by Geothermal Resource Technologies, Inc. under the supervision of Charles Remund, Ph.D:, Director of Engineering.

This report provides a general overview of the test and procedures that were used to perform the thermal conductivity test along with a plot of the data in real time and in a form used to calculate the formation thermal conductivity. The following average formation thermal conductivity was found from the data analysis.

⇒ Formation Thermal Conductivity = 1.44 Btu/hr-ft-°F

Due to the necessity of a thermal diffusivity value in the design calculation process, an attempt was made to estimate the average thermal diffusivity for the encountered formation.

⇒ Formation Thermal Diffusivity ≈ 1.01 ft^2/day

A copy of the original collected data is available either in a hard copy or an electronic format upon request.

Test Procedure

The procedure for the formation thermal conductivity test is as follows:

1. Connect the u-bend ground heat exchanger pipe to the portable FTC unit.
2. Connect the data acquisition unit to the wiring harness in the FTC unit.
3. Connect the FTC unit to 240 volt power supply (collected data indicated the average voltage over the analyzed test region was 237.7 volts).
4. Fill and purge air from the FTC unit.
5. Insulate the exposed u-bend pipes (leading from the well bore surface to the FTC unit).
6. Simultaneously turn on the heating elements and initiate the data acquisition device.
7. Routinely monitor that the power supply remains connected and the water level of the fluid reservoir within the FTC unit stays at an acceptable level.
8. After the test is completed, turn off heating elements, the circulation pump, and the data acquisition device.

Data Analysis

Geothermal Resource Technologies, Inc. uses the "line source" method of data analysis. The line source equation used is not valid for early test times. Also, the line source method assumes an infinitely thin line source of heat in a continuous medium. If a u-bend grouted in a borehole is used to inject heat into the ground at a constant rate in order to determine the average formation thermal conductivity, the test must be run long enough to allow the finite dimensions of the u-bend pipes and the grout to become insignificant. Experience has shown that the amount of time required to allow early test time error and finite borehole dimension effects to become insignificant is approximately ten hours.

In order to analyze real data from a formation thermal conductivity test, the average temperature of the water entering and exiting the u-bend heat exchanger is plotted versus the natural log of time. Using the Method of Least Squares, the linear equation coefficients are then calculated that produce a line that fits the data. This procedure is normally repeated for various time intervals to ensure that variations in the power or other effects are not producing erroneous results.

Through the analysis process, the collected raw data is converted to spreadsheet format (Microsoft Excel®) for final analysis. A copy of this data can be obtained either in a hard copy or electronic copy format at any time. If desired, please contact Geothermal Resource Technologies, Inc. and provide a ship-to address or e-mail address at one of the following:

Phone: (972) 390-1537
Fax: (972) 390-1851
E-mail: askouby@grti.com

Formation Thermal Conductivity Test Report

Date ..... May 5 - 7, 2001
Location ..... Hartselle, AL

Borehole Data

Undisturbed Soil Temperature ..... Appox. 64° F[1]
Borehole Depth ..... 200 ft.
Borehole Diameter ..... 6"

Drill Log .....

Dirt (wet)	0 – 12'
Sandy Limestone	12 – 30'
Light – Medium Limestone	30 – 75'
Shale	75 – 140'
Medium Hard (light-colored) Limestone	140 – 200'

U-bend Size ..... 1 in. HDPE
U-Bend Length ..... 200 ft.
Grout Type ..... Tailings
Grouted Portion ..... NA
Grout Solids ..... NA

Test Data

Test Duration ..... 25.1 hrs.
Average Power ..... 3,204 W
Calculated Circulator Flow Rate ..... 8.1 gpm
Total Heat Input Rate ..... 10,936 Btu/hr

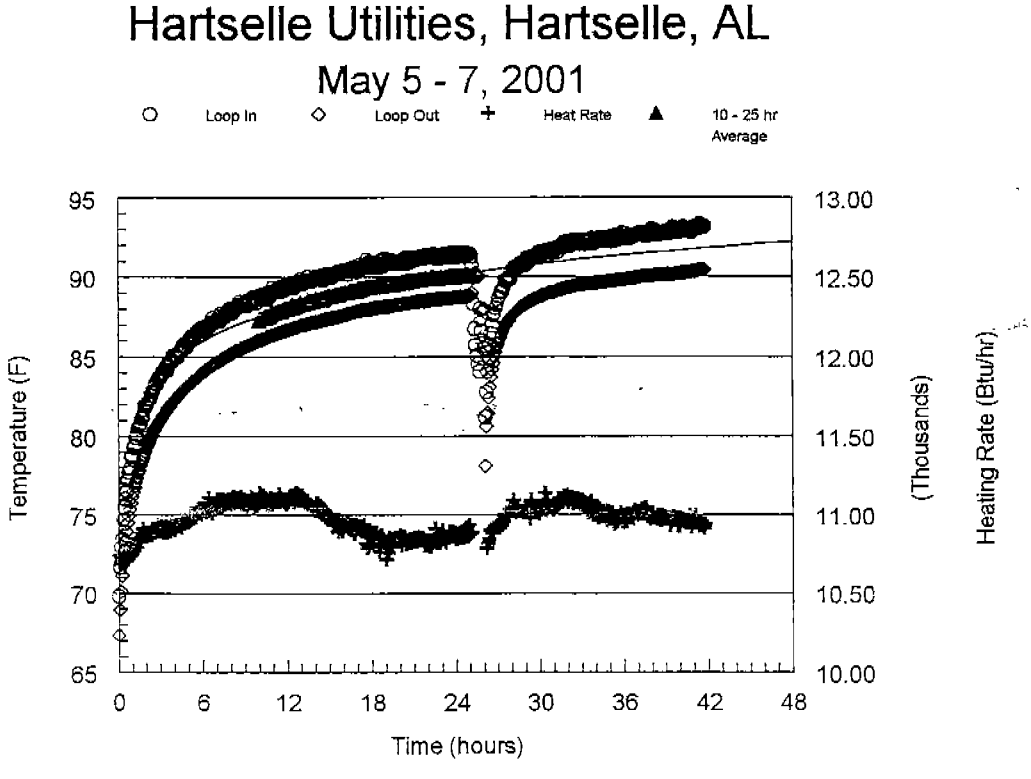

Figure 1: Temperature versus Time Data

Line Source Data Analysis

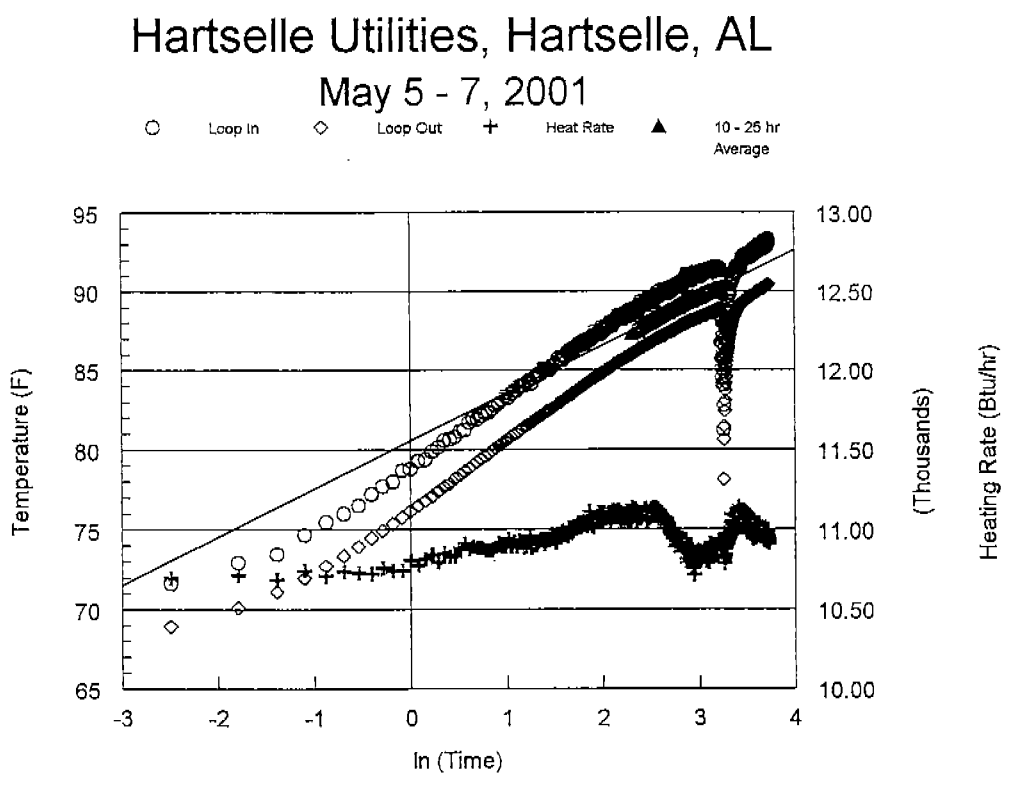

Figure 2: Temperature versus Natural Log of Time

Time Period	Slope: a_1	Average Heat Input (Btu/hr-ft)	Thermal Conductivity (Btu/hr-ft-°F)
10 – 25.08 hrs	3.01	54.68	1.44

The temperature versus time data was analyzed using the line source analysis for the time period shown above. Due to an interruption in power at approximately 25 hours, an average linear curve fit was applied to the data between 10 and 25.08 hours. The slope of the curve (a_1) was found to be 3.01. The resulting thermal conductivity was found to be 1.44 Btu/hr-ft-°F.

Estimated Thermal Diffusivity

The reported drilling log for this test borehole indicated that the formation consisted of approximately 35% shale and 65% limestone. Heat capacity values for shale and limestone were calculated from specific heat and density values listed by Kavanaugh and Rafferty (Ground-Source Heat Pumps - Design of Geothermal Systems for Commercial and Institutional Buildings, ASHRAE, 1997). A weighted average of these values based on the indicated formation was used to develop an average heat capacity for the formation. An estimated diffusivity value was then found using the calculated formation thermal conductivity and the estimated average heat capacity. The thermal diffusivity for this formation was estimated to be approximately 1.01 ft^2/day.

Est. Average Heat Capacity (Btu/ft^3 °F)	Thermal Conductivity (Btu/hr-ft-°F)	Est. Thermal Diffusivity (ft^2/day)
34.1	1.44	1.01

1. "Undisturbed Soil Temperature" was determined from data collected during the test start-up sequence. Due to the fact that the test bore was completed within a short time period of when the test was started, it is likely that there was some residual heat present at start-up resulting in a slightly high reported value.

Mid-South Geo & Water Resources, Inc.
P.O. Box 297 • Lebanon, TN 37088-0297
Phone: (615) 444-0423 • Fax: (615) 444-0427

WORK ORDER

01029

Date 5-2-01

Job HARTSELLE Utilities AL. Phone _____

Address _____ County _____

Requested On: _____

Start Drilling _____ Complete Drilling _____

Total Depth _____ Depth to Rock _____

Casing Set _____ Type & Size _____ Bit Type/Size _____

Total Yield _____ Water Zones _____ Quality Water _____

DEPTH	FORMATION
0 - 12	Drift
12 - 25	Shell
25 - 50	Lime with Seam of Shell @ 30' 12-18"
50 - 75	Lime with Several Layers of Shell
75 - 100	Shell
100 - 125	ALL Shell
125 - 150	Shell to 135' then Lime to 150'
150 - 175	Lime
175 - 200	Lime